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ESTIMATING THE COSTS OF HUMAN SPACE EXPLORATION

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The strategic plan for NASA's new exploration initiative begins:

> *On July 20, 1989, the President of the United States committed the nation to a major initiative to explore space. The goal of this initiative is human exploration of the Moon and Mars as soon as possible within the constraints of national resources.*
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> *From several years of studying alternative strategies and debating the relative merits of national investments in space exploration has emerged a consensus; i.e., that expanding human presence and activity beyond Earth orbit is an appropriate and inevitable long term focus for the nation's space program.*[1]

The plan states three strategic themes: incremental, logical evolutionary development; economic viability; and excellence in management. All of these intricately involve the cost estimation process, and, as will be shown, will be completely dependent upon the engineering cost estimator for success.

The purpose here is to articulate the issues associated with beginning this major new government initiative, to show how NASA intends to resolve them, and finally to demonstrate the vital importance of a leadership role by the cost estimation community.

The Demand for a New Management Paradigm

The exploration program objective, as stated in the *NASA Strategic Plan*, emphasizes early accomplishments, but also recognizes that the environment today is substantially different, and that whatever is done must be done within the limits of realistic budgets.

This presents a double challenge to NASA, where the length of a human mission spacecraft development program has approached a decade. For a new era of space exploration to begin at all, it is believed, early milestones must be set which are challenging and attractive to those who must provide program resources (the National Space Council, OMB, Congress), oversight bodies which have sent strong signals that multibillion dollar exploration programs requiring decades to reach fruition are not in NASA's future. NASA must therefore provide early, visible, worthwhile milestones in exploring space.

At the same time, costs must be reduced. Generally, compressing a given task into a much shorter period of time will greatly increase the annual funding required. NASA must find ways to compress and at the same time *lower* annual funding requirements. Already, the experienced engineer/estimator will begin to have concerns. Accomplishing these challenges one at a time is difficult enough, but to accomplish both at once is beyond the paradigm of conventional aerospace program management, on which almost all of our estimation methods are based.

Another example of the problems with the conventional aerospace management paradigm is illustrated by the case of the Space Station program. That program struggled to lower annual budgetary requirements by reducing the mission content of the program; but the more the program is modified, the more changes are incurred, the *higher* the total program cost, and the more pressure on annual budgets. Reducing content can achieve the most significant cost savings before the program is started. Once underway, content reductions often exacerbate an already bad cost situation.

The situation is made even worse by the absence of good tools. Every cost model employed by the aerospace industry today (with perhaps one or two exceptions) merely predicts the future based on the behavior of the past. If, then, extrapolation of past behavior will not produce the desired result, how can cost models based on that behavior serve us at all? NASA has learned that they cannot. In fact, they can become the tools of those who oppose new programs, to *prove* to the Congress and the Administration that undertaking of the grand new adventure is folly. Of course, the point would not have been proven at all, but the perception of proof is at least as powerful as proof itself. One can look for situations of this nature to arise within the next few years. The cost estimator, then, can become the enemy of progress. Or, as will be demonstrated, he or she can lead the way to change.

Struggle as we will within this old paradigm, we will not be able to resolve the dual challenges of lowering annual costs substantially while significantly reducing program length. Impossible. So, what can be done? Should NASA simply go the President and admit defeat? To do that would probably doom what remains of the human adventure in space, and not only jeopardize future programs, but raise the question of the continuation of current programs as well.

When a problem cannot be resolved within one paradigm, it is obviously necessary to change to a new one. But before that new paradigm is defined, a direction must be established, and a model created for the new. To change course without a new destination would be equally disastrous. The research done by NASA to identify that new model follows.

A Summary of the Cost Challenges Facing Exploration

Much of the planning of any new venture involves matching demands for resources with the predicted supply. Within the old paradigm, the supply of resources has often been predicted only by estimating the demand. In former times, this process has worked because the aerospace and defense industries have generally received ample support from the nation to create this norm.

However, the norm is today being threatened. As each new human space venture since the initial Apollo lunar landing has been launched, the availability of resources has become increasingly scarce. The Space Shuttle, a program designed to lower the cost of placing humans and cargo into space, defeated its own *raison d'etre* when it was forced, for reasons of annual budget limits, to eliminate its completely reusable booster, and to limit the availability of on-board autonomy which would have reduced the expense of ground control and checkout.

Similarly, Space Station Freedom was beset from the outset with mission compromises caused by annual budgetary limits, and became a much less capable facility than was originally conceived by NASA. Each year the program suffered further and further content reductions in an attempt to meet annual cost constraints.

Today's situation has found the nation even less able to pay for large, new manned space programs than ever before in our spacefaring history. But it has taken some time for this realization to influence the program planning paradigm. For example, as recently as 1991, the Advisory Committee on the Future of the U.S. Space Program was making recommendations to the NASA Administrator which, while recognizing that there were budgetary constraints, were predicated on the availability of greatly increased NASA budgets (see Figure 1).

As NASA began its studies of human exploration missions under the old management paradigm, the cost models employed pro-

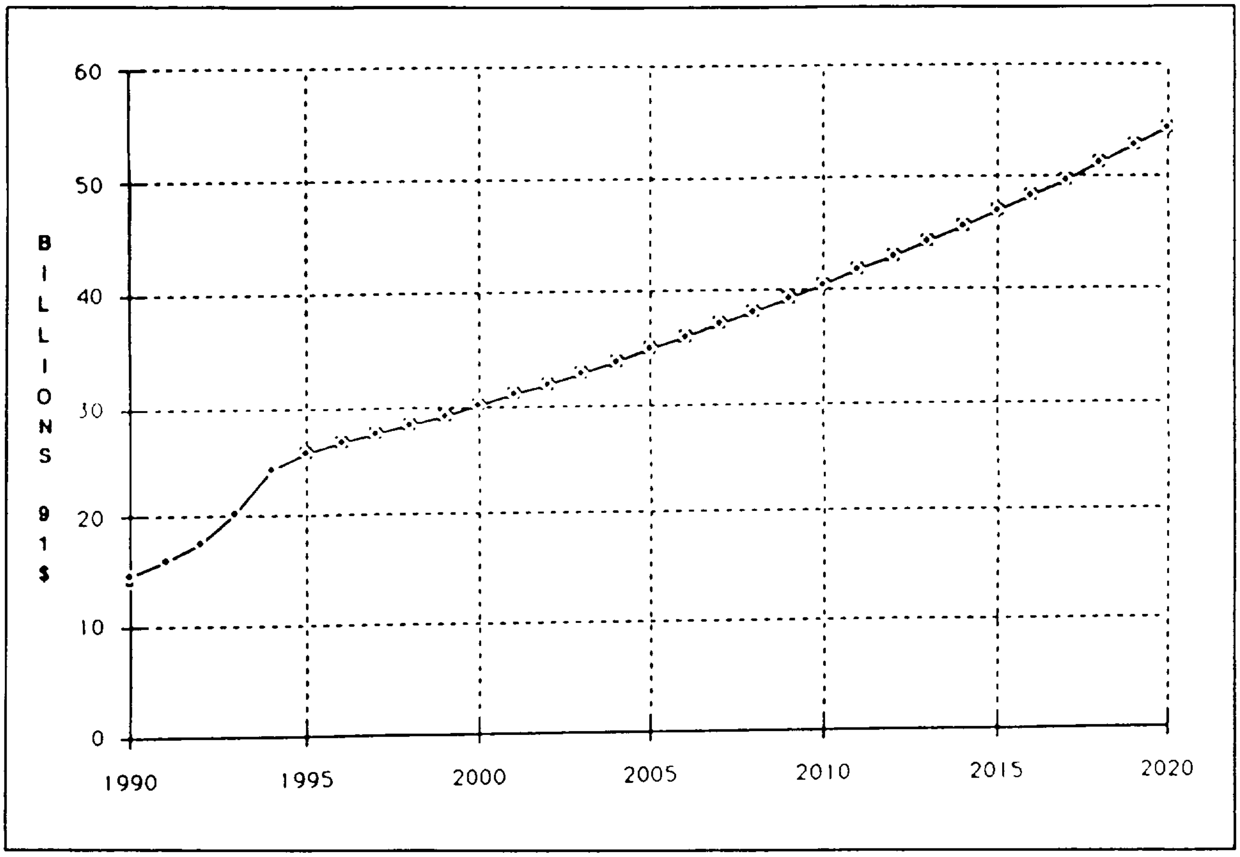


Figure 1. Budget Assumption of the Advisory Committee on the Future of the U.S. Space Program

duced estimates such as those shown by the middle curve of Figure 2. Overlaid with the budget projections of the Advisory Committee on the Future of the U.S Space Program (top curve, Figure 2), there seemed to be no reason to doubt that exploration had a bright future.

However, when better budgetary estimates were made with econometric models and with full understanding of the true likelihood of NASA budget growth (lower curve of Figure 2), the dilemma became apparent to some for the first time.

Four Things Which Must Be Done

To resolve the dilemma of budget growth, NASA must do four things. First, full attention must be paid to the mission statement of the opening paragraph: "to the Moon and to Mars as soon as possible, within the constraints of national resources." With a focus on the purpose of human exploration, the need for much of the content of previous planning exercises can be questioned, and missions constructed which contain only mission-related items.

Second, existing NASA and other governmental resources must be found and leveraged. For example, much of the money currently being spent by NASA on science and technology is fully applicable to the purposes of human exploration; however, some mission focus must also occur in these areas. The use of other federal resources can include the use of national laboratories and DoD assets, and these are being investigated.

Third, NASA must implement a new management paradigm which does things faster, smaller, and less expensively, using the enormous cost leverage which results from cultural change.

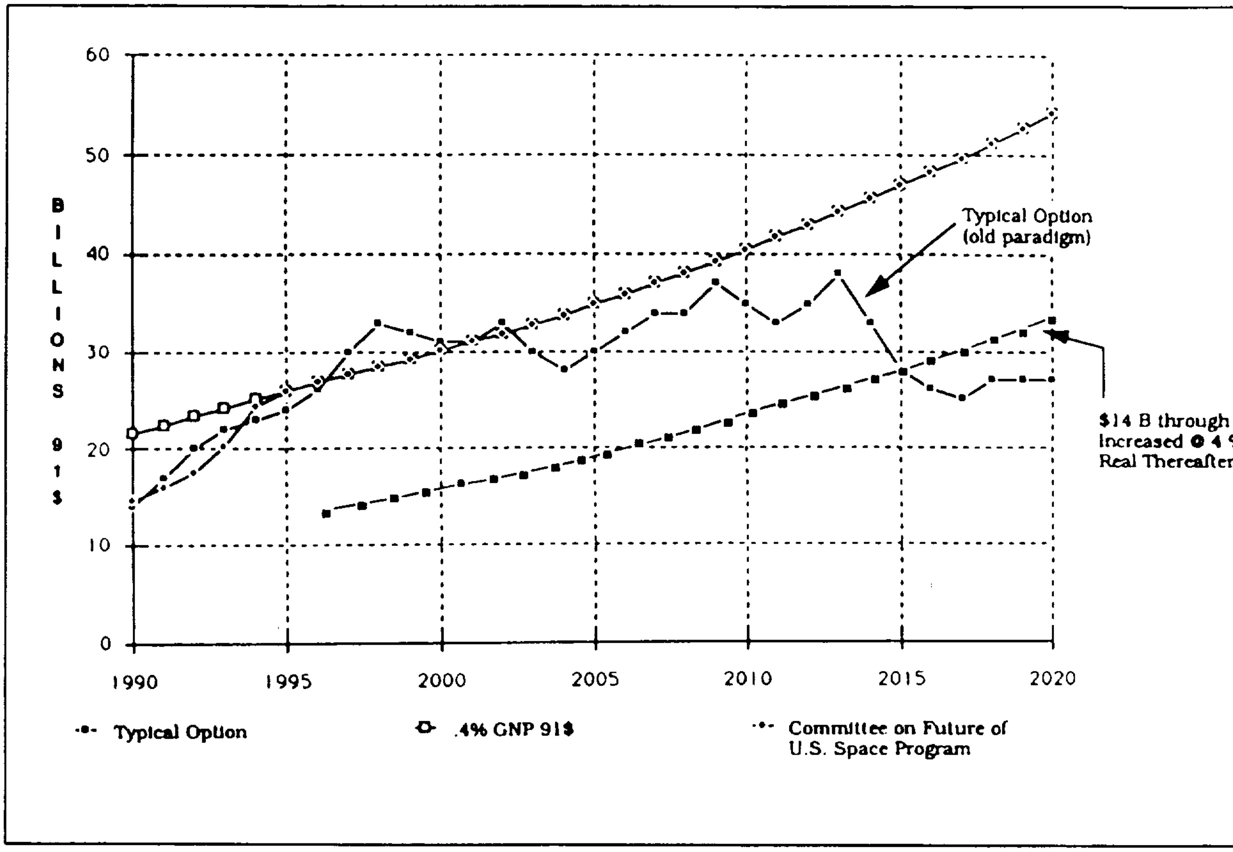


Figure 2. Comparison of Budget Availability Models

And finally, some new resources must undoubtedly be found for NASA. These will be much more likely to be forthcoming if the Agency once again gains the full confidence of the Congress and other oversight groups by demonstrating competence and efficiencies associated with the change to the new management paradigm.

Benchmarks for the New Paradigm

NASA is conducting research to identify benchmarks, guidelines, and processes for the low cost, short schedule paradigm. Extensive interviews have been conducted and analyses performed to identify high technology programs which have been done under different management norms, and which have resulted in high performance, low cost, quickly developed products.

Results of the interviews, summarized in Figure 3, indicate a wide consensus on the part of those successful managers interviewed, that NASA should confine itself more to the development of good, performance-based requirements, and establish a more arms-length relationship with the private sector to allow the power of the competitive marketplace to produce excellent products.

Historically, the highly interactive relationships between NASA and its contractors have produced excellent products, but program change rates have been in the thousands per year, and high costs and long development schedules are typical. Contractor awards should be based on the performance of products as demonstrated in mission performance. Taken altogether, the findings of this research, as summarized, provide very useful benchmarks for designing future program management processes. But do these findings describe a feasible set of conditions?

Another part of the NASA research has dealt with the identification of programs which have been accomplished more under the described new set of conditions than under the existing aerospace paradigm. Programs like the XR-71, the F-117, and the YF-16 (Lockheed, Lockheed, and General Dynamics, respectively) have demonstrated that high technology programs can be done very quickly (all of these programs produced flying aircraft in approximately two years) and at costs significantly below those which would have resulted from the old paradigm.

However, much more work is needed by the industry to plan and execute an orderly transition from one culture, one paradigm, to the new paradigm for NASA space exploration. The cost estimator can play a key role in the process.

Cost and Culture: The New Calculus of Cost Analysis

Cost estimation methods employed by the aerospace industry for program planning are usually parametric in nature, although some detailed estimating is used for special purposes which do not readily lend themselves to performance or size-based parametrics.

In most parametric estimation, for reasons that parametric estimators seek the best possible analogies from their historical databases, the implicit assumption is that a new program will be a product of basically the same cultural and management conditions (the same paradigm) as programs of the recent past. However, when this assumption is made for exploration programs, the resulting estimates exceed realistic budgetary expectations.

The ingredients of successful low-cost, high technology programs are well known and universally recommended by successful program managers interviewed

- Use government only to define requirements
- Keep requirements fixed: once requirements are stated, only relax them; never add new ones
- Place product responsibility in a competitive private sector
- Specify end results (performance) of products, not how to achieve the results
- Minimize government involvement (small program offices)
- Insure that all technologies are proven prior to the end of competition
- Utilize the private sector reporting system: reduce or eliminate specific government reports
- Don't start a program until cost estimates and budget availability match
- Minimize or eliminate government imposed changes
- Reduce development time: any program development can be accomplished in 3 to 4 years once uncertainties are resolved
- Force people off of development programs when development is complete
- Incentivize the contractor to keep costs low (as opposed to CPAF, CPFF of NASA)
- Use geographic proximity of contractor organizations when possible
- Use the major prime contractor as the integrating contractor

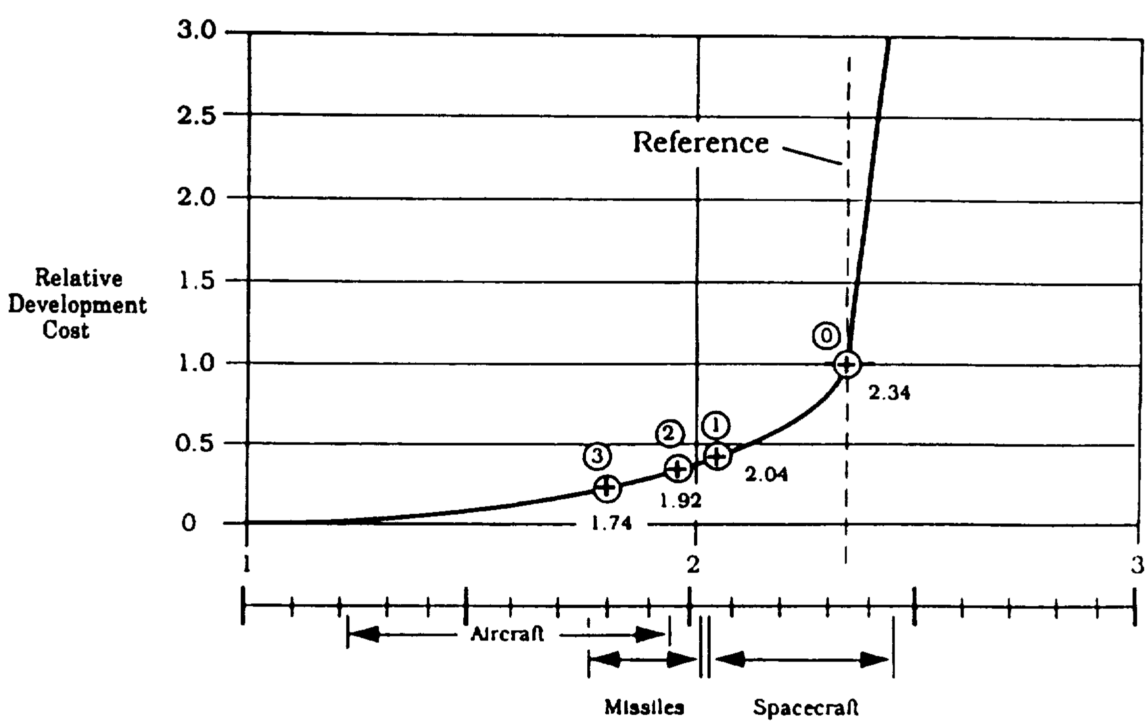
Figure 3. Benchmarking Lessons Learned from Interviewing Successful Program Managers

Therefore, one *must* conclude that, if major exploration programs are to be performed, significant cultural change to a new paradigm is an absolute necessity. However, except for the G.E. PRICE series of models, the aerospace industry cost estimator is not equipped to deal quantitatively with cultural change as an explicit variable using the existing tools and databases. It has, therefore, been necessary to construct a new type of cost model, which, instead of predicting costs from "technical" and performance parameters, *will predict the cultural levels required to produce a given cost outcome.*

Working with the then-RCA PRICE Systems organization, NASA performed a study to determine the effects of various culturally imposed standards on costs. The study results[2] demonstrated conclusively that, while there is correlation between cost and such things as government-imposed parts traceability requirements, major differences still exist in program costs which can only be explained by the organizational "manner of doing business," or culture of the developing agent.

These results have recently been repeated by Kelley Cyr of NASA's Johnson Space Center and employed in the development of a new series of cost models. Figure 4, based on a statistical analysis of several hundred points of data, portrays the quantified relationship between cost and development culture.

In the current environment, this type of cost equation provides the needed utility to relate costs to program management and manufacturing culture. Particularly in government aerospace product acquisitions, the highest levels of product performance have been for over a generation the object of most development efforts in the industry. This has created a culture where program cost, while highly



Small changes in development culture can have huge influences on the costs of space programs

Figure 4. Effect of Development Organization Type on Program Development and Production Cost

important, has not generally been treated as a critical design parameter.

In this climate, it is not surprising that many design engineers and program planners are generally not well equipped to deal with cost as an explicit parameter. Who, then, is available to provide the leadership which will be so vital to the conversion of our industry to lower cost, shorter schedule norms?

Who is closest to the necessary data? Who has the best understanding of the dynamics of engineering processes as they are influenced by costs and schedules? Who (often) has training in both engineering and business practices? Who is most often the one who bears a major responsibility for any major cost reduction activity? It it proposed here that there is no one better equipped than the company cost estimator. The case can be made that the cost estimator is best able to provide answers to all of these questions.

In the case of the exploration initiative, the activities of the cost estimation team will have the most significant influence of any on the future success of the venture. That team must not only develop compelling cost estimates, but they must also lead the way in providing the rationale, the supporting arguments, to provide cogent reasons why NASA can truly accomplish what it proposes (such as returning humans to the Moon by 1999) within the available budgets. It is also the cost estimation team who must provide the information for the design teams to utilize in developing requirements for low-cost, early missions. They may be the only team who can complete the bridge to the new paradigm. If they fail at this, the entire venture will probably fail to be accepted by the Congress and the Administration.

The aerospace industry cost estimating community holds the future of the United States Space program in its hands. While this community is not unto itself sufficient to develop the new initiative, it is vitally necessary.

Conversely, the cost estimating community is totally sufficient to prematurely end the life of American space exploration, at least for this generation. It is far easier to develop strong arguments for why the nation cannot afford to send humans to the Moon and to Mars than it is to prove that it cannot afford not to do it. It is far more comfortable to fall back on that which has served us well in the past and hold to the old culture, to stay with the old paradigm. It is far easier to use our existing, culturally-bound costing methods than it is to seek methods which can point the way to changes that may brighten the future of our entire profession, if not our industry.

The job of cost estimators has never been easy. The results of their work have often determined whether or not their company wins or loses a major competition. But today, it is the cost estimators who wield the enormous power of life or death over the future of the United States space exploration program. It is earnestly hoped that this awesome responsibility will not be taken lightly.

References

1 *Space Exploration Initiative Strategic Plan, Building Tomorrow's Program Today* (Unpublished Draft). Washington, DC, National Aeronautics and Space Administration, Office of Exploration. February 1992.

2 *Equipment Specification Cost Effect Study* Phase 2 Final Report. Cherry Hill, NJ, RCA PRICE Systems Division. November 1971.